Global Survey of Concentric Gravity Waves in AIRS images and ECMWF analysis

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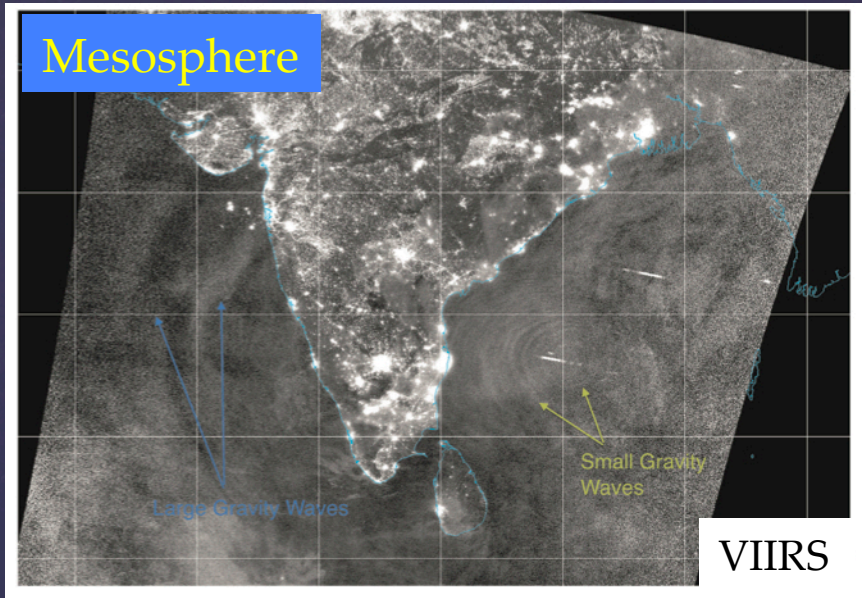
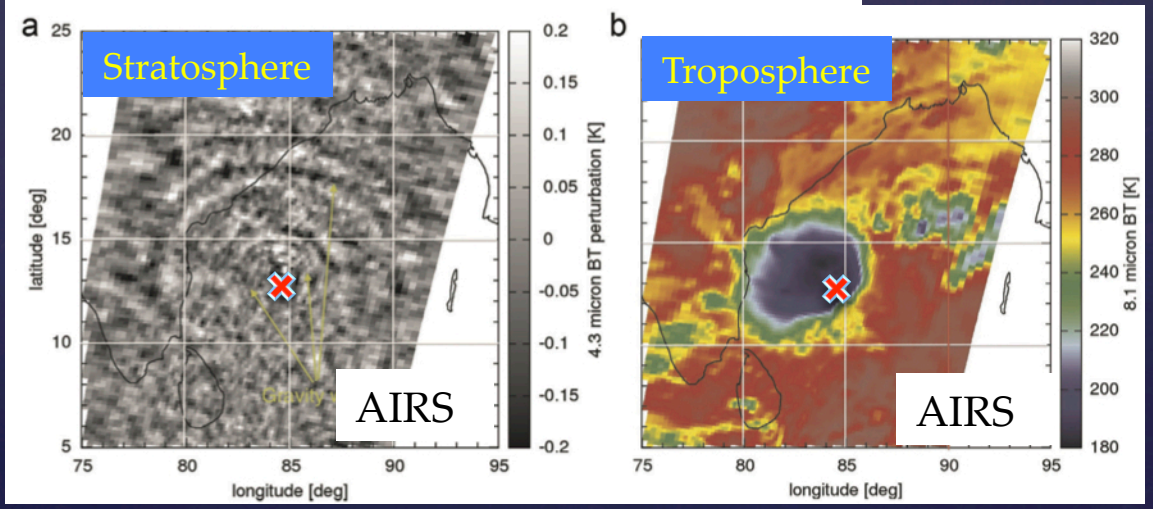
What is concentric gravity wave (CGW)?



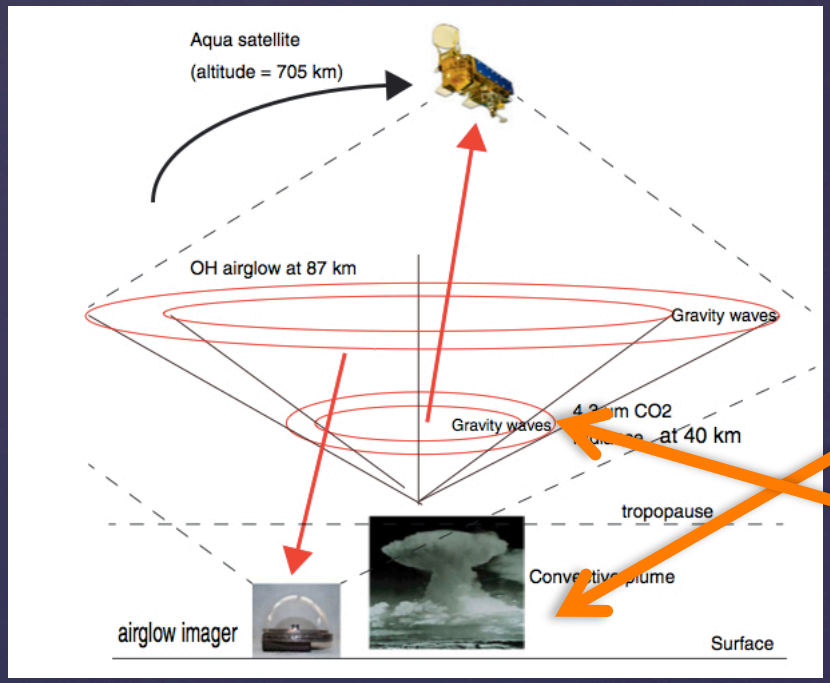
- CGW morphology looks like a group of concentric rings
- Tropical cyclone tends to generate two types of concentric rings
- The larger wavelength one is discernable by AIRS



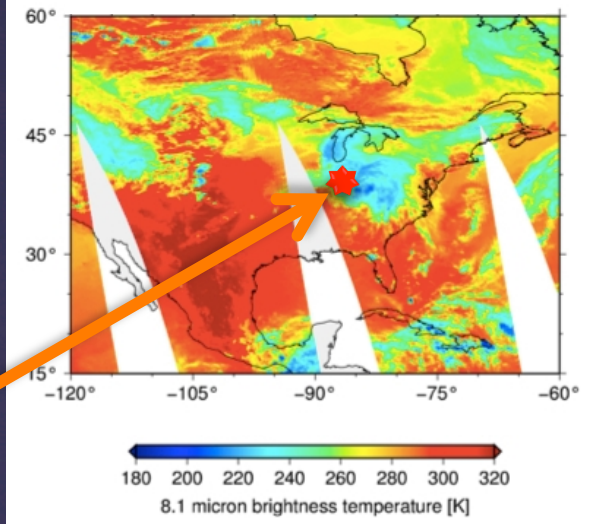
(Yue et al., 2014, JASTP)


Tropopause
Search: 949000065

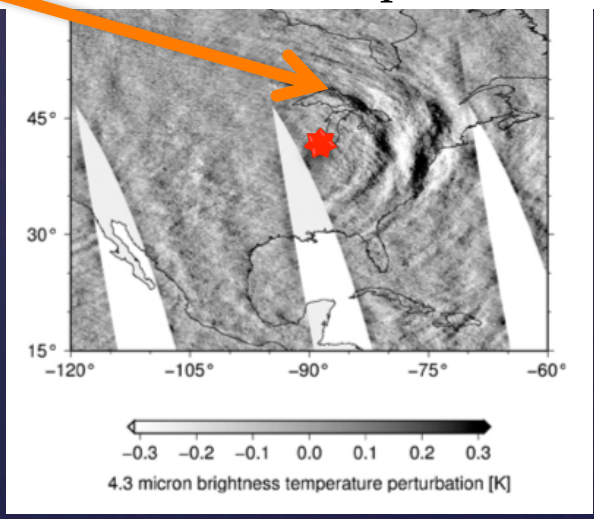
Motivation 1: concentric ring waves are important to the upper atmosphere



AIRS cloud radiance



AIRS 4um radiance perturbation

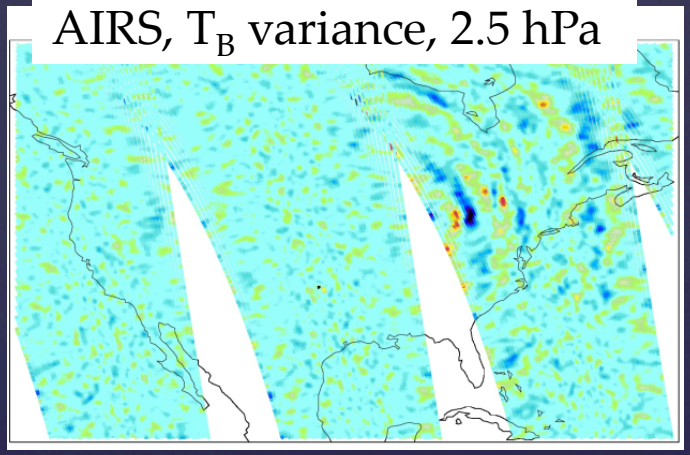


(Yue et al., 2013, JGR)

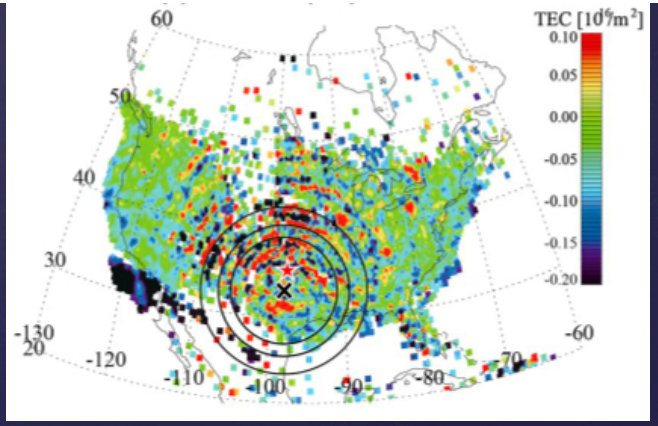
Concentric rings can even impact the GPS signals

Aftermath of 2013 Moore Tornado

AIRS, T_B variance, 2.5 hPa

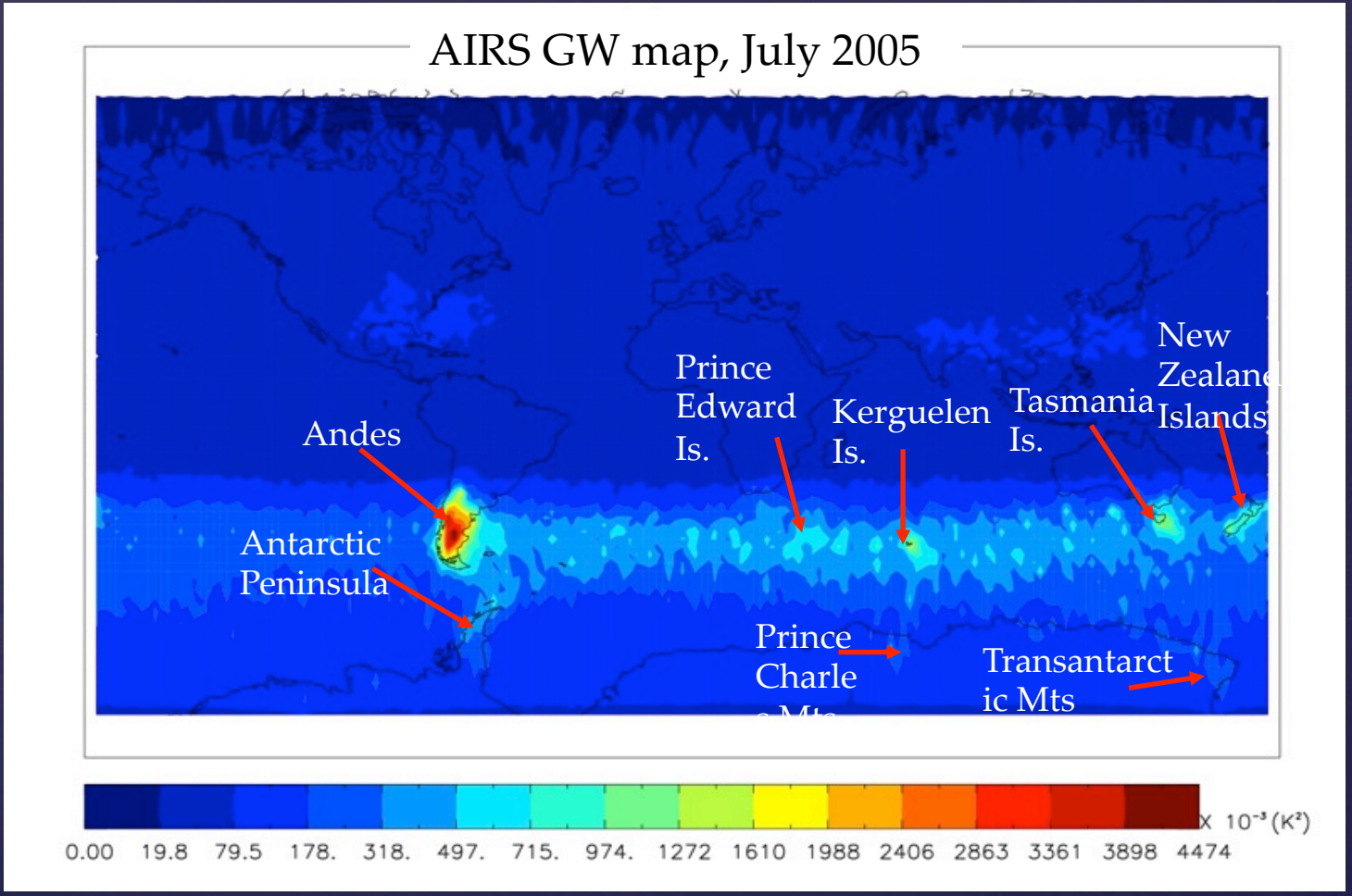


GPS, Total Electron Content, ionosphere



(Nishioka, 2013, GRL)

Motivation 2: except topography, what else causes the belt of GW activities in the Southern ocean?



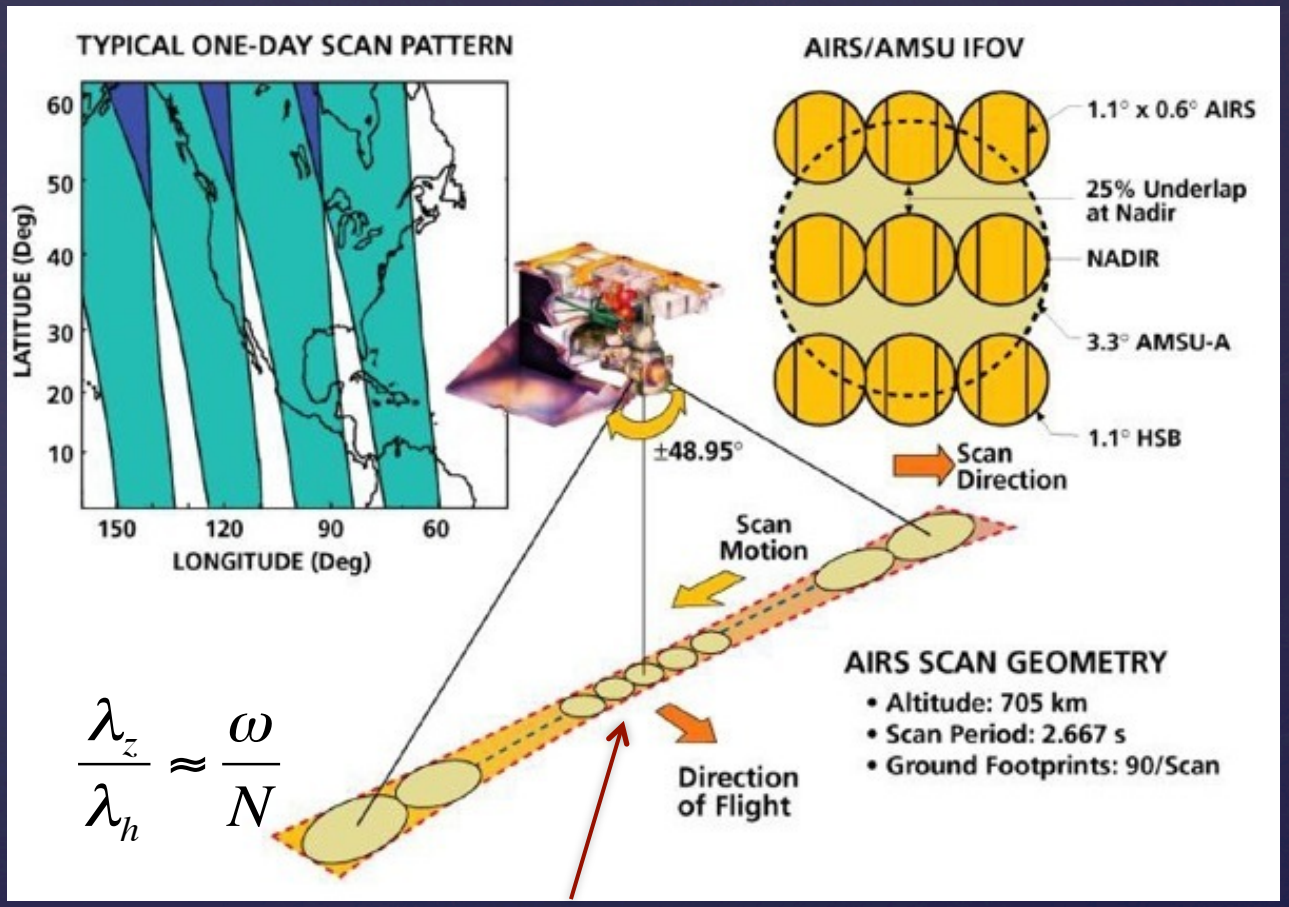
(Gong et al., 2012, ACP)

Outline

- Ring Detection Algorithm
- First CGW climatology from AIRS obs.
- ECMWF resolved CGW climatology and comparison with AIRS obs.
- Conclusions and future works

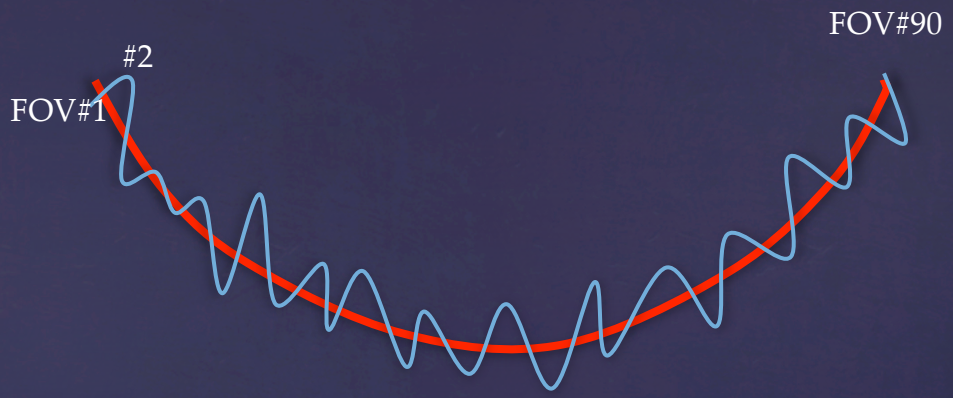
AIRS (Atmospheric Infrared Sounder) on NASA Aqua

- Footprint: 1.1° x 0.6° (13.5 km x 7.4 km)
- Scan range: ±48.95°
- Compared to AMSU-A, the detectable frequency range increases
- Ascending: local early afternoon
- Descending: local mid-night



90 AIRS field-of-view (FOV) in each cross-track scan
Swath width: ~1670 km

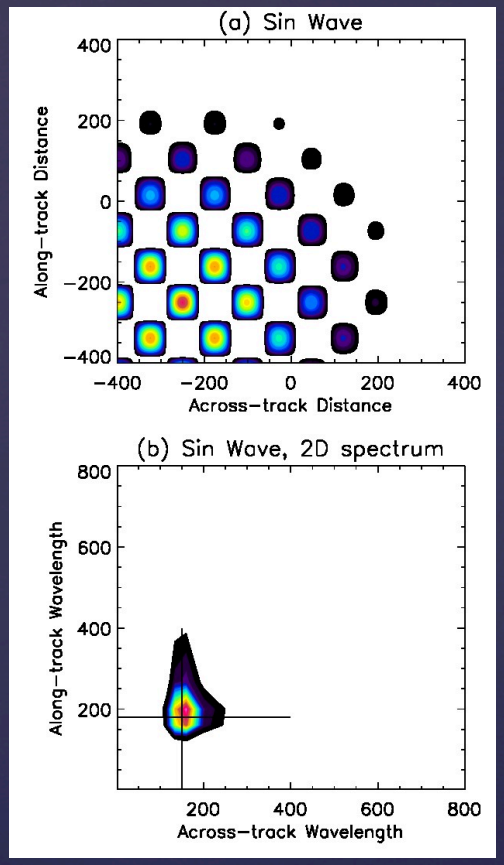
AIRS Radiance Perturbations



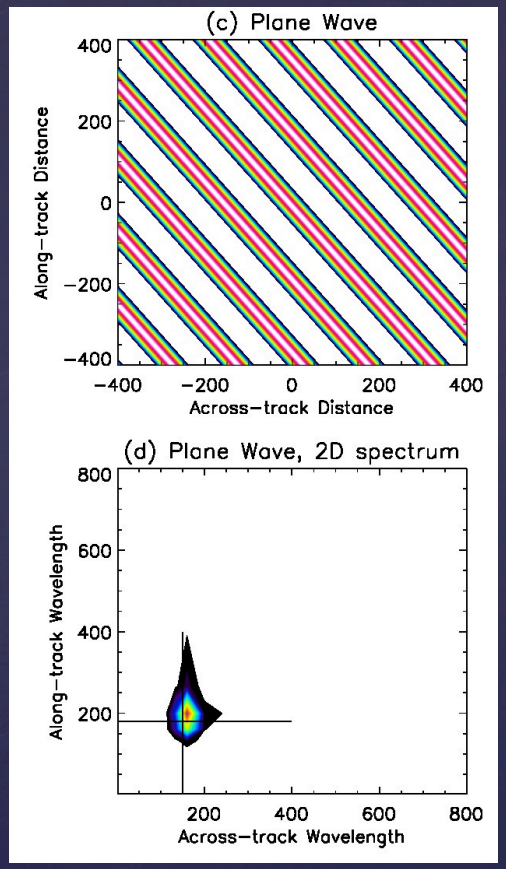
- Gravity wave variance (σ_{TB}^2) can be derived from the AIRS radiance perturbations
- For this study, we only remove the limb brightening effect to keep all kinds of GWs as many as possible.

Method to identify a ring on an AIRS image

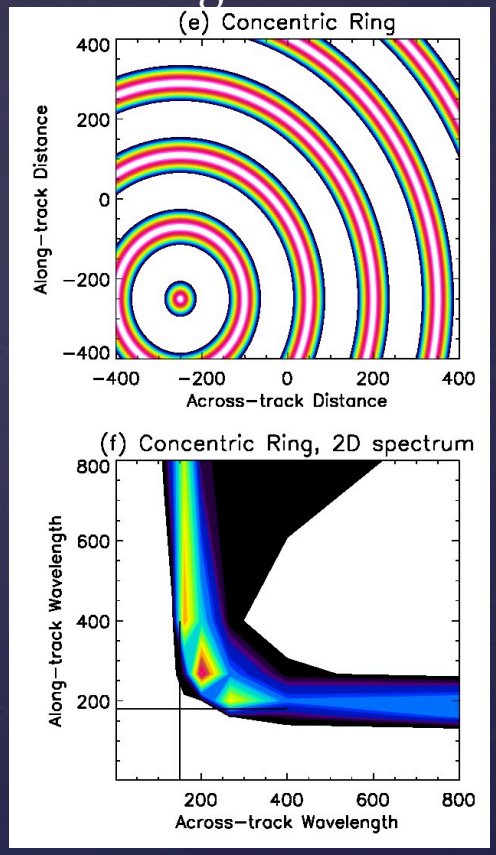
Sine Wave



Plane Wave

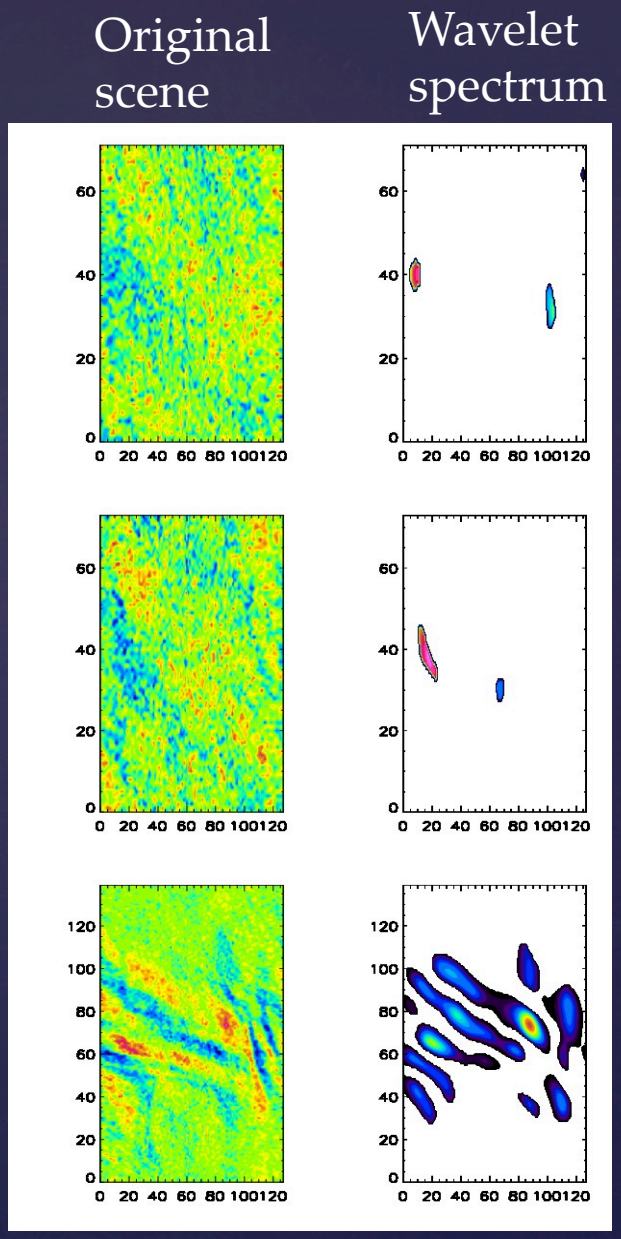


Ring Wave



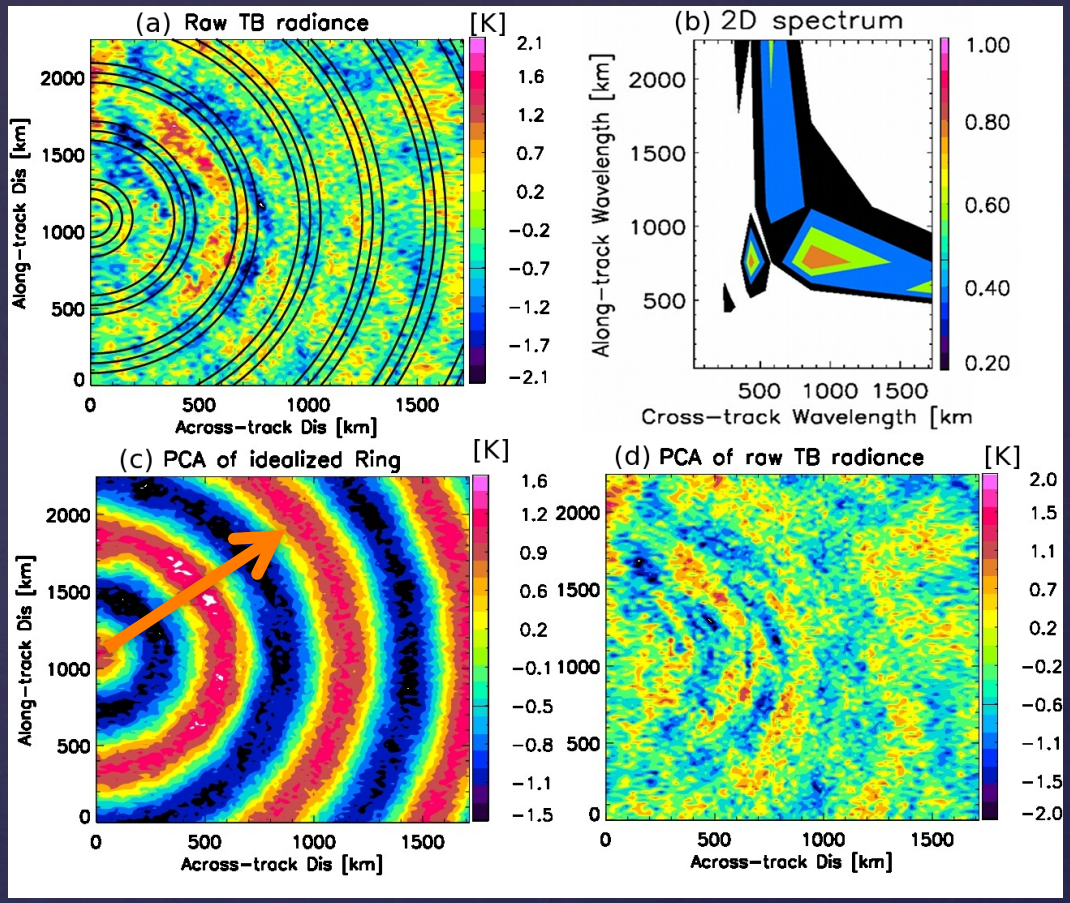
- **L-shape 2-D FFT spectrum is the key**

1. In each ascending or descending orbit, using wavelet transform to identify several major wave events;
2. If two scenes are separated by 2 degrees in latitude, we consider them as two independent event; otherwise, one event. Buffer zones are add at two meridional sides;
3. The scene is then interpolated to mesh grids in both directions;
4. Decompose the image by 2D Fourier transformation. If an L-shape feature is identified, the along-track and across-track wavelength combinations are used to re-construct the ring;

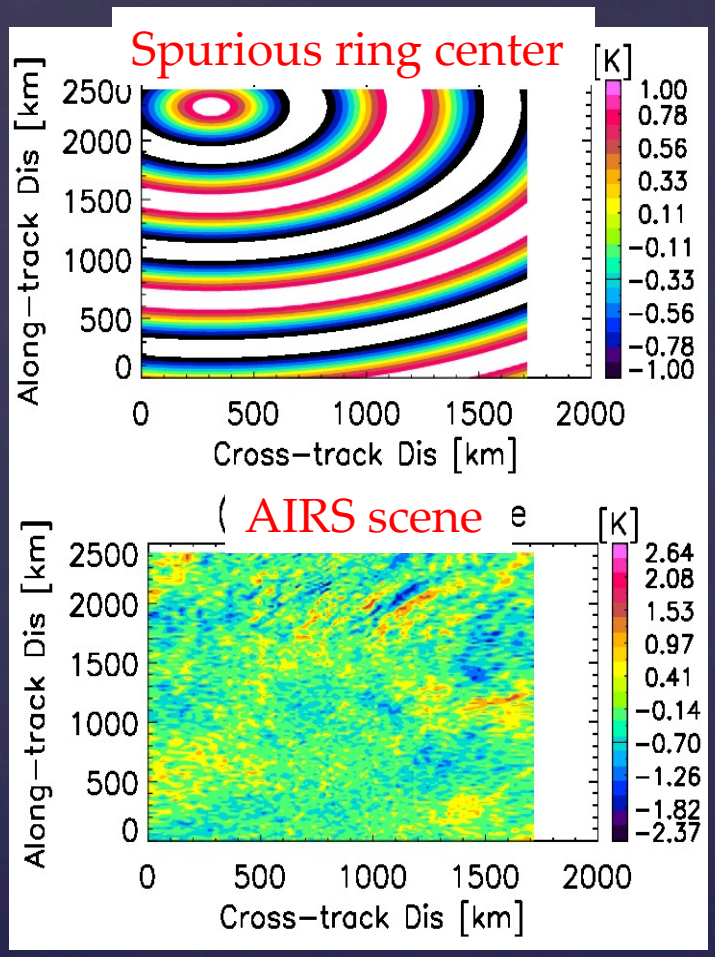


5. Patrol the ring center to each grid to find the largest positive correlation with the original scene; If the maximum correlation passes certain threshold, a concentric ring event is confirmed;

6. A principle component analysis (PCA) is used to identify the wave phase propagation direction;



- Some times, the ring could be spurious if the wave curvature is not so apparent…

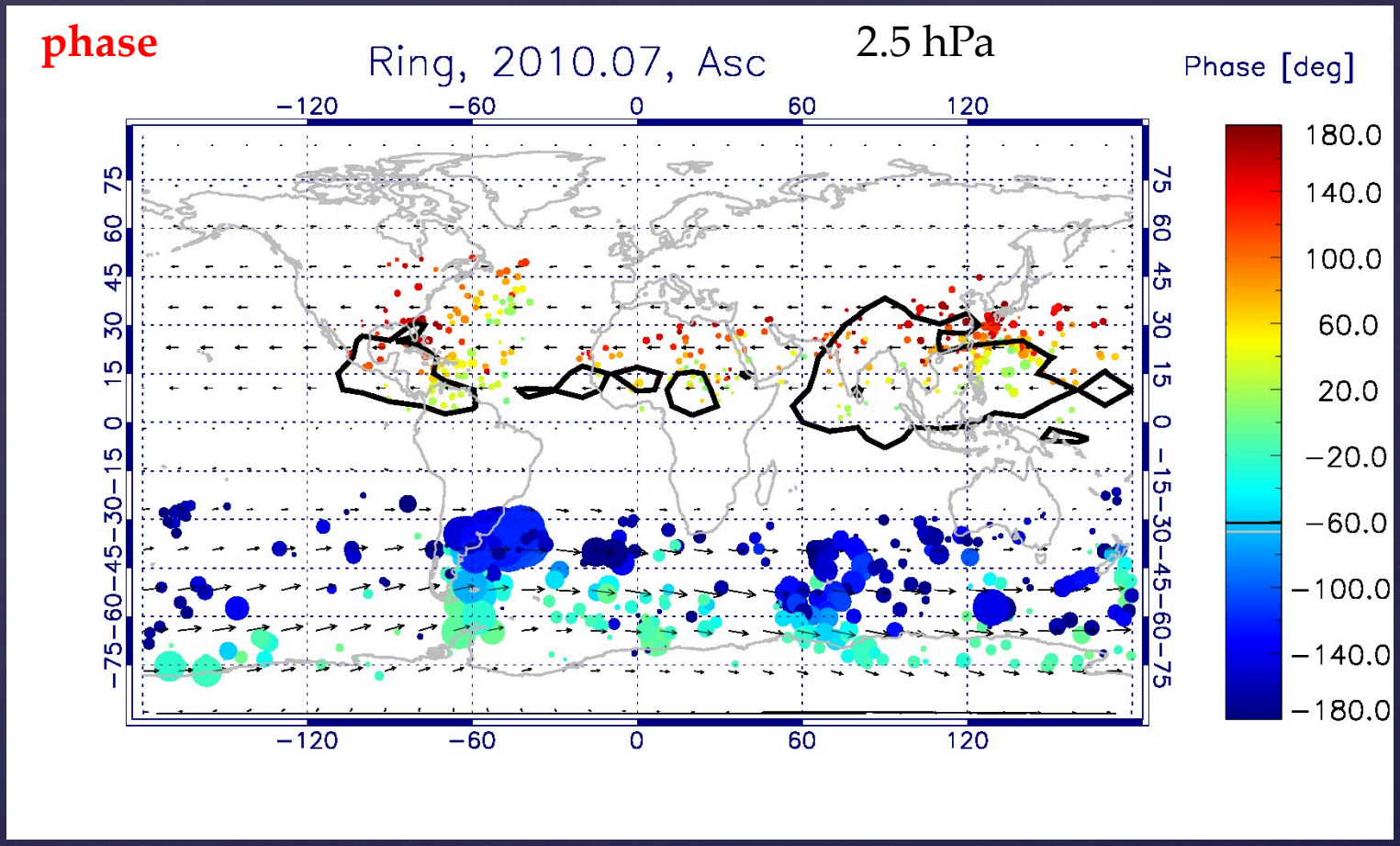


7. Only if the zonal phase propagation direction determined from step 6 is against the local zonal wind that we think we are "correct" (wind filtering effect).

- This is a very important assumption!

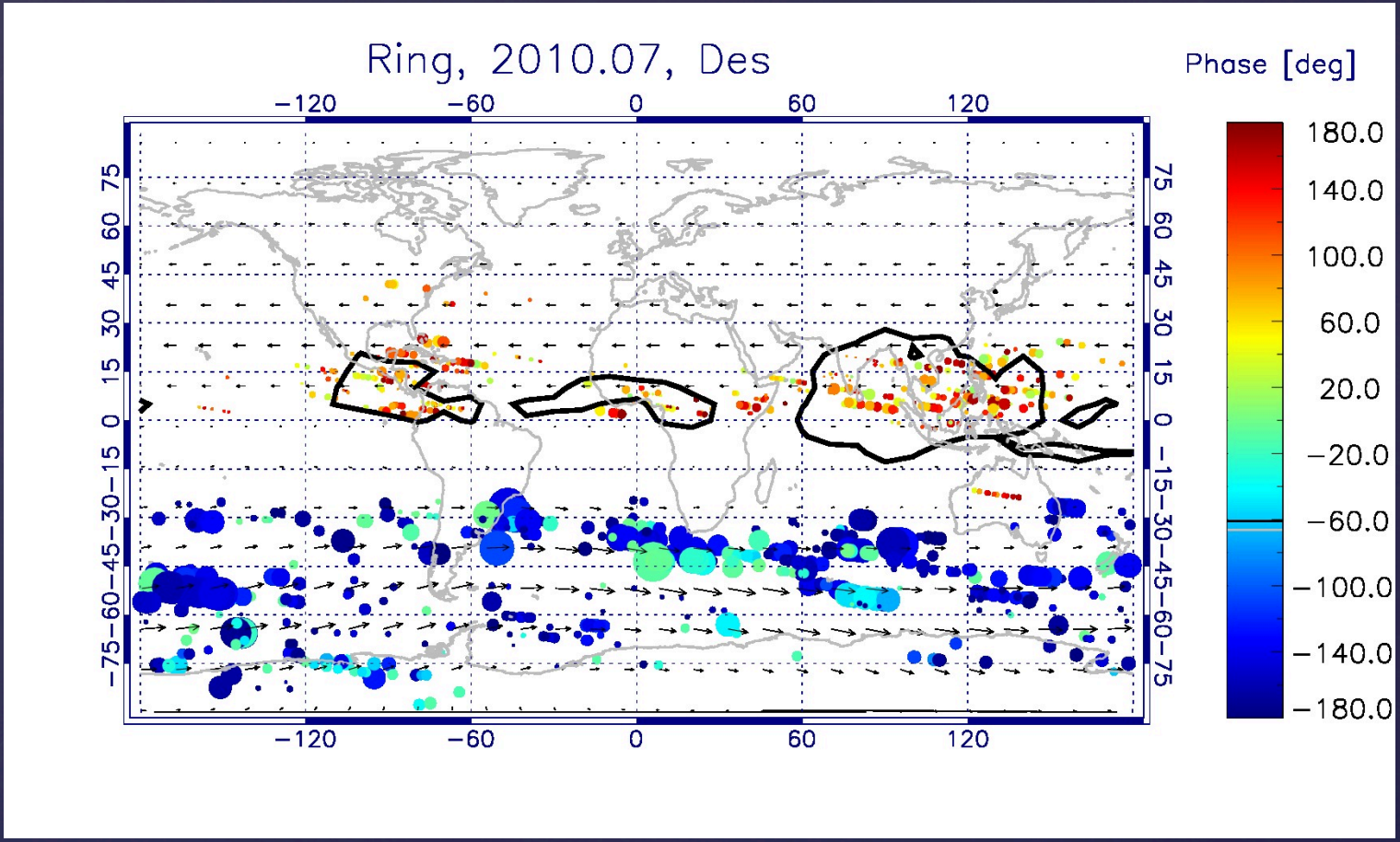
Now, here comes the exciting part

– rings propagate toward the jets, in both hemispheres, in day time!



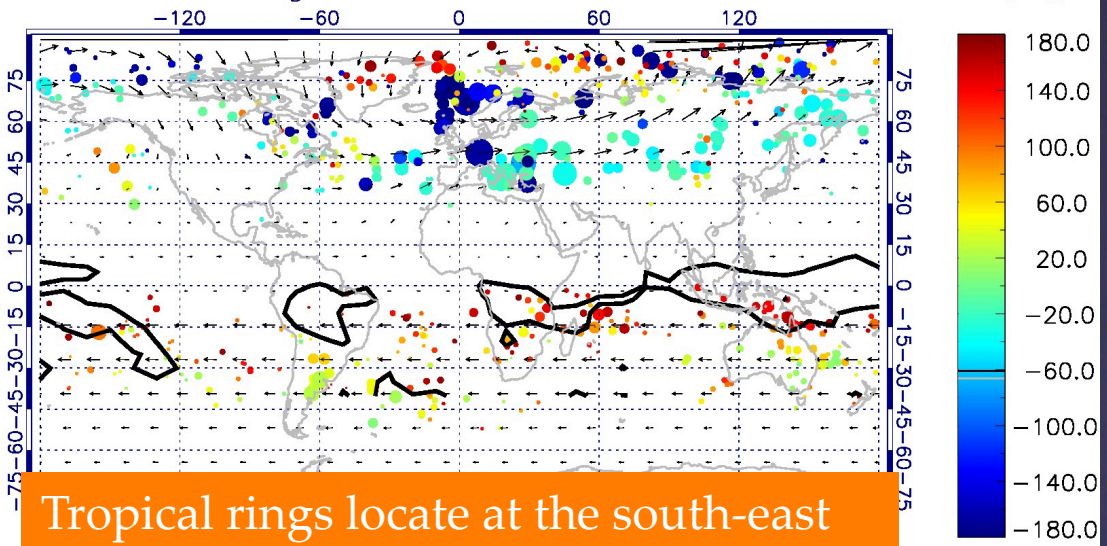
- The zonal components slow down the jets
- The meridional components propagate into the jets

In nighttime, inward meridional preference disappear

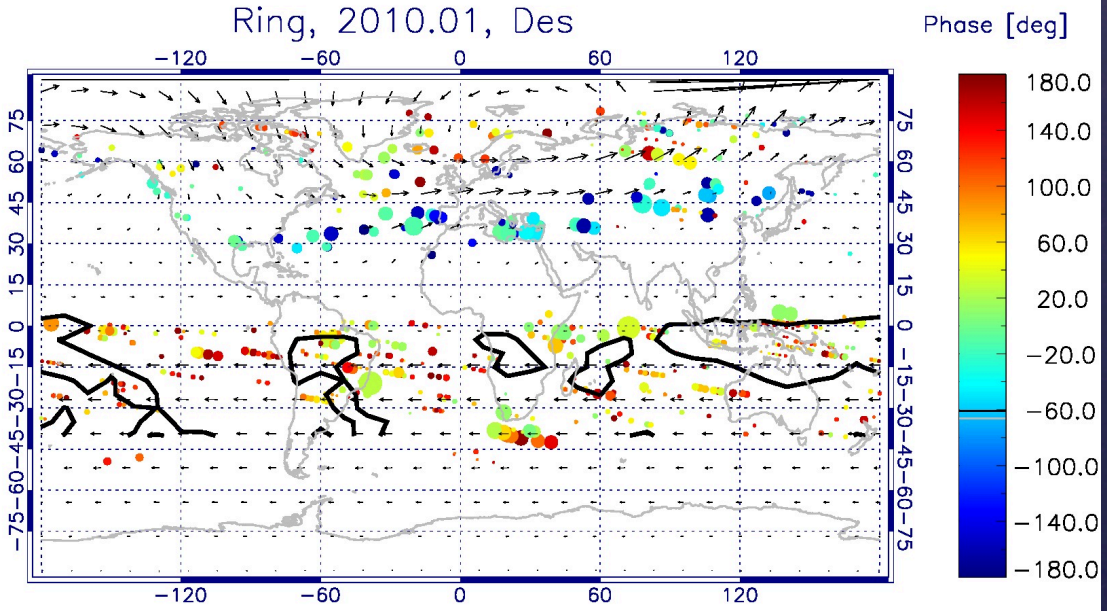


- Rings are not only present above deep convections, but also above polar-night jet
- Strong diurnal variation in meridional propagation direction, wave generation location and occurring frequency (not considered in GCMs).

phase



Tropical rings locate at the south-east of deep convective centers.



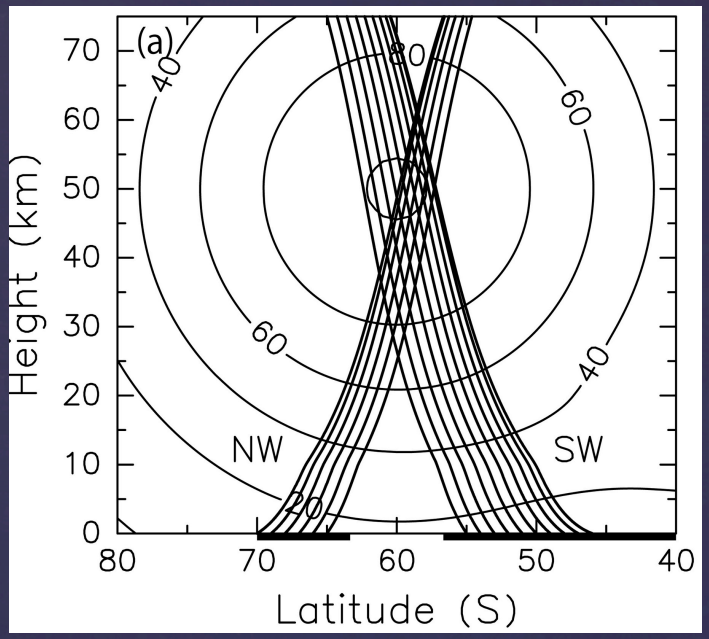
Ascending orbit:
local early afternoon

Strong meridional convergence

Descending orbit:
local mid-night

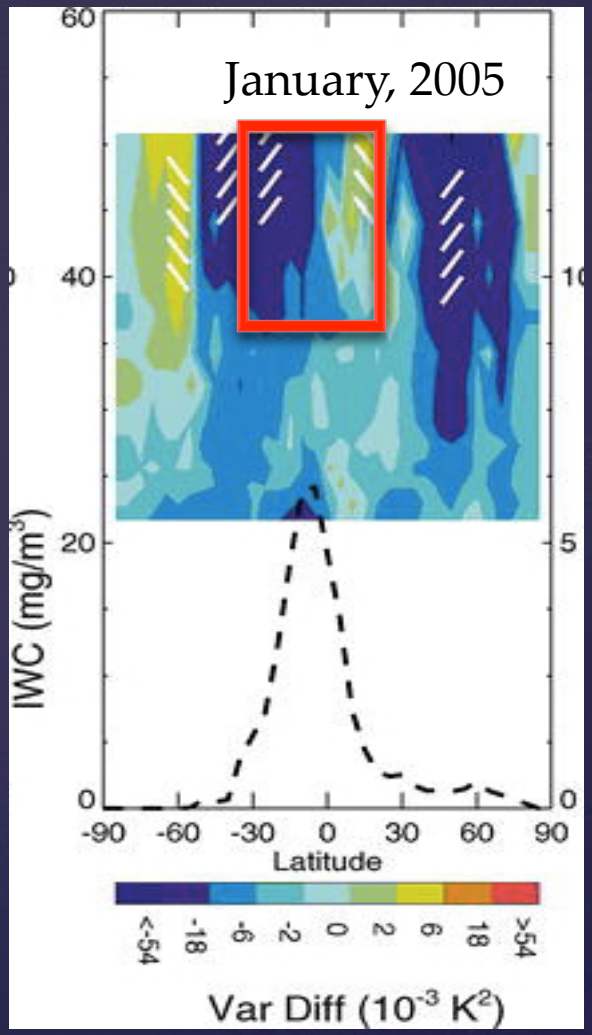
Meridional convergence only in the high-latitude

Ray-tracing experiment in Japan High-resolution GCM



(Sato et al., 2012, JAS)

Aura MLS



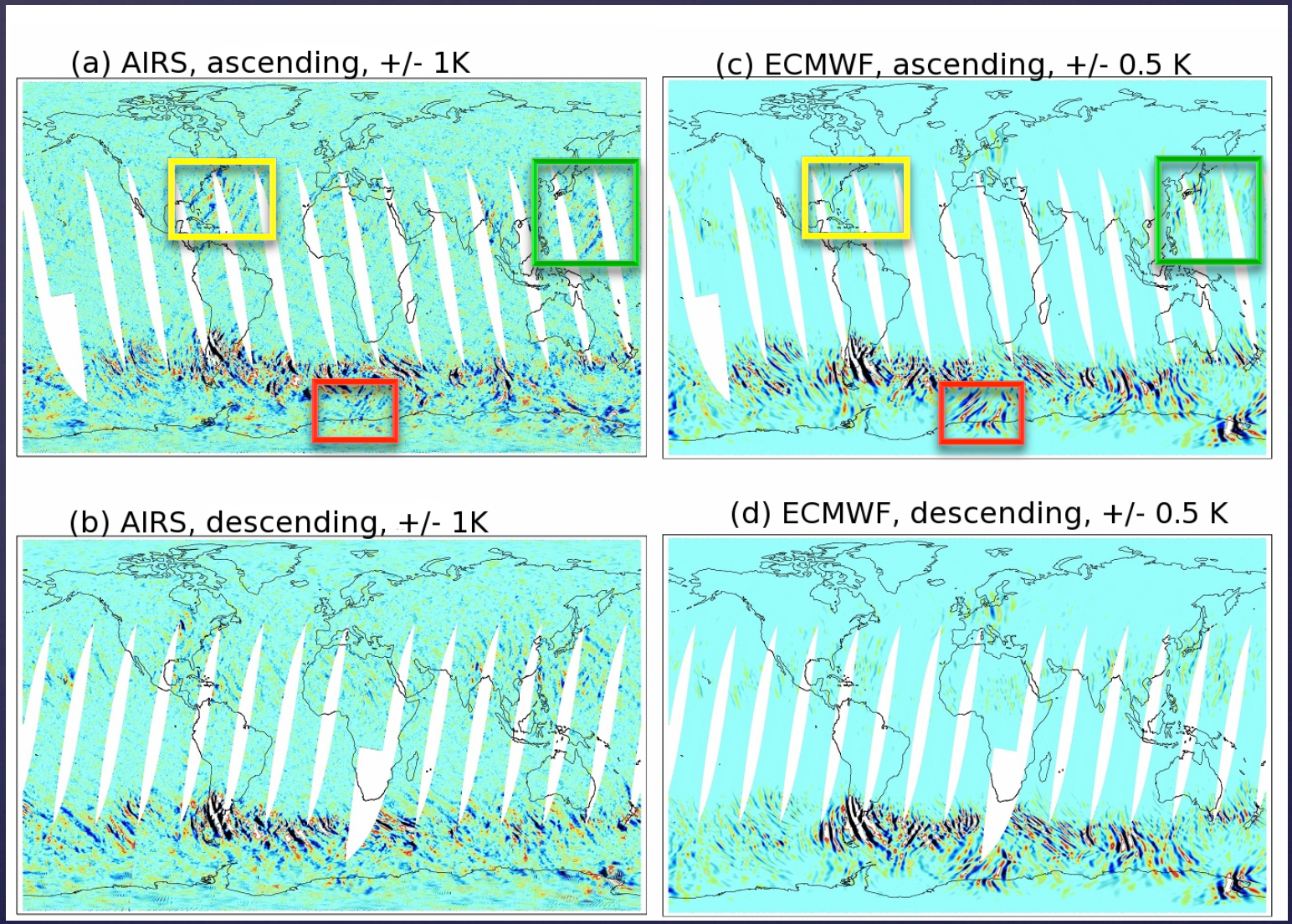
(Wu & Eckermann, 2006, JAS)

Comparison between AIRS and ECMWF resolved concentric rings

- ECMWF began to adapt 16 km resolution since year 2010, meaning that ECMWF analysis should be able to resolve GWs with ~ 100 km horizontal wavelength.
- So what's the concentric ring map look like in ECMWF?
- Does increase model resolution help on resolving CGWs?

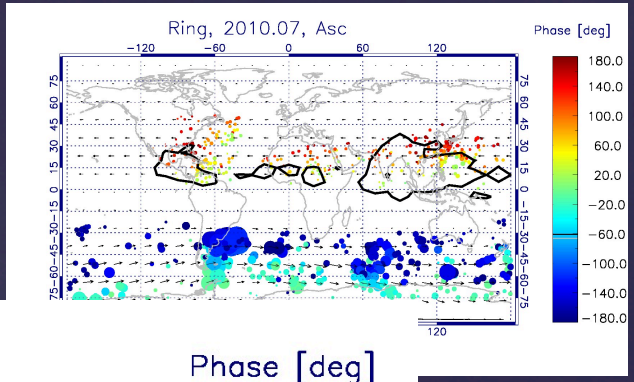
AIRS, 2.5 hPa, 07/11/2010
(after 3pt smooth)

ECMWF, 2.5 hPa, 07/11/2010
(no smoothing)



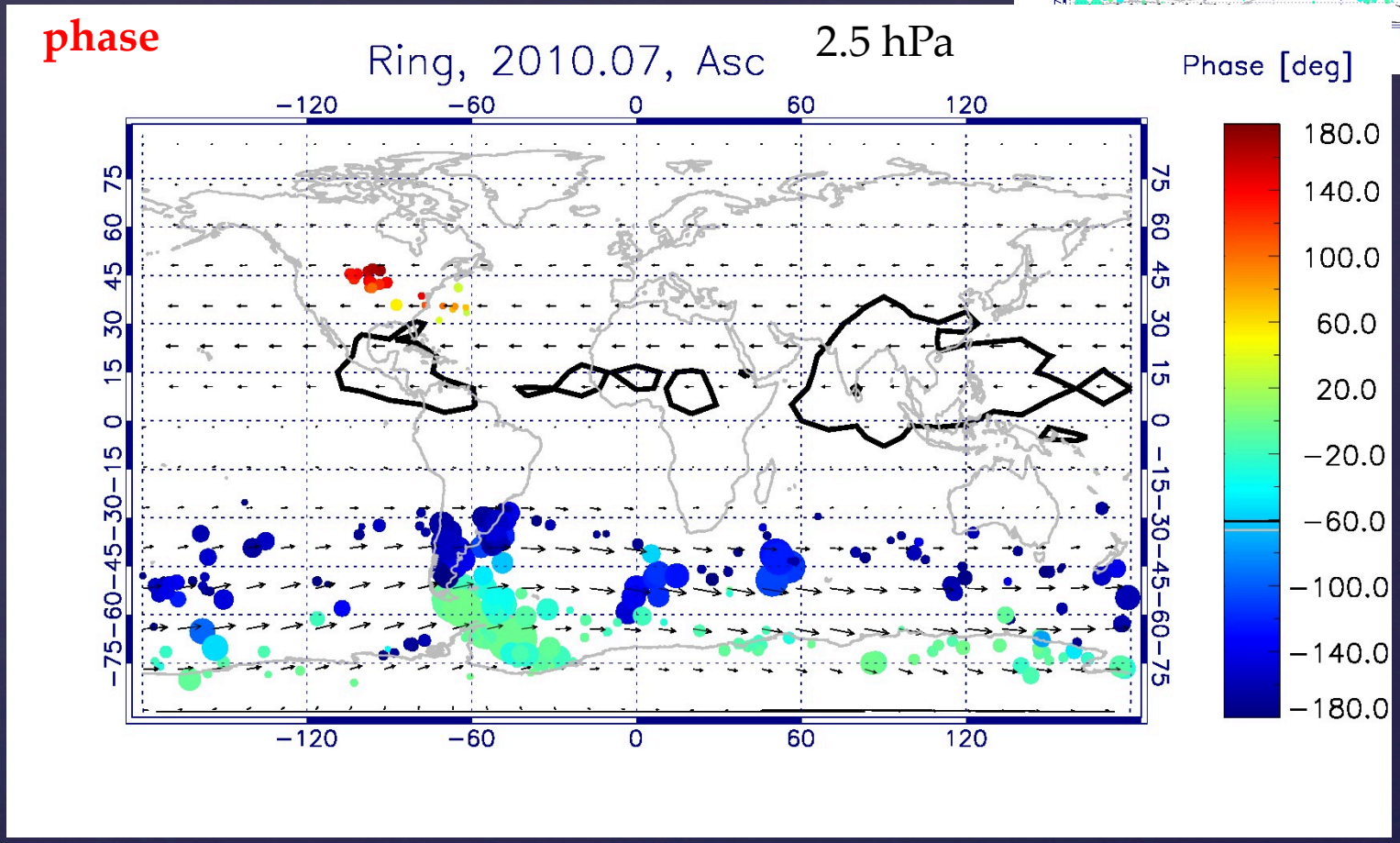
- Model resolved GWs are weaker, but the general pattern is quite agreeable.

AIRS



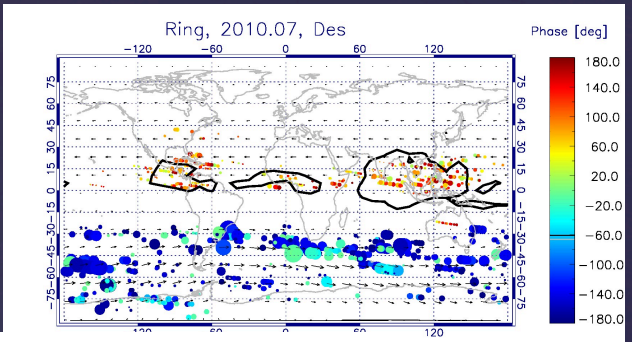
ECMWF, phase direction

phase

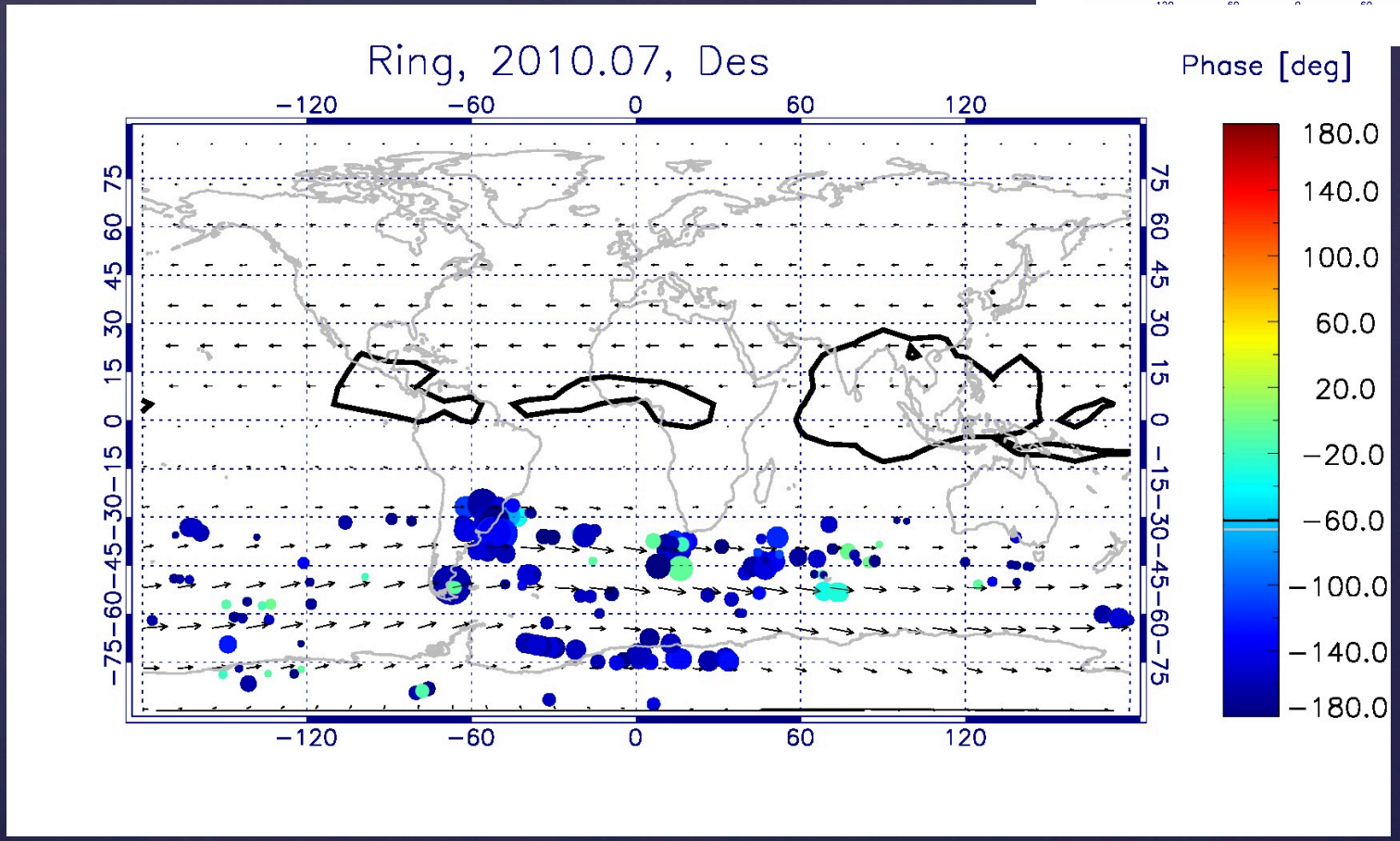


- ECMWF generally has the correct meridional propagation direction
- ECMWF has too few resolved convective rings.

AIRS



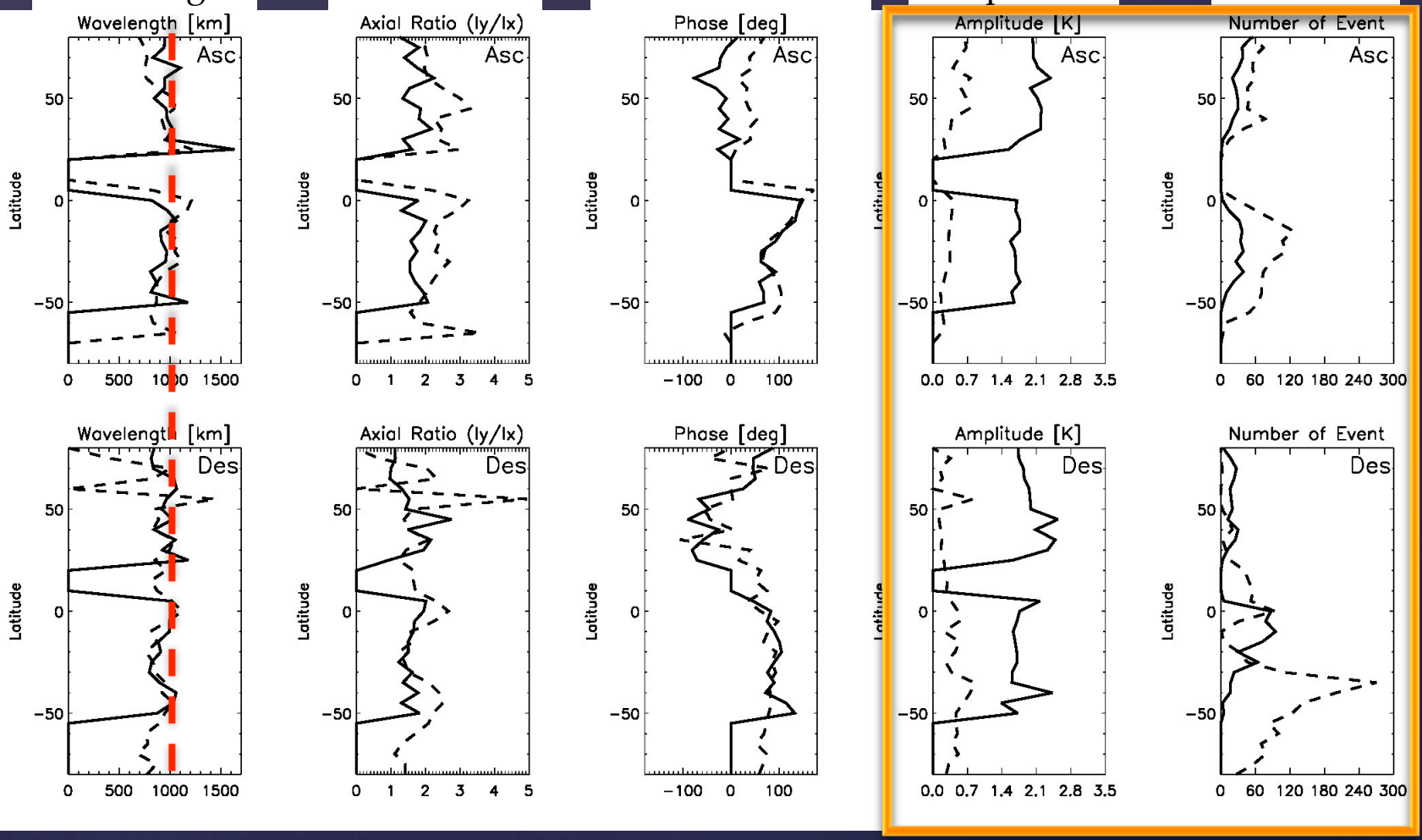
ECMWF, phase direction



- ECMWF has too few convective rings and jet rings in mid-night.

January, 2010 (T799)

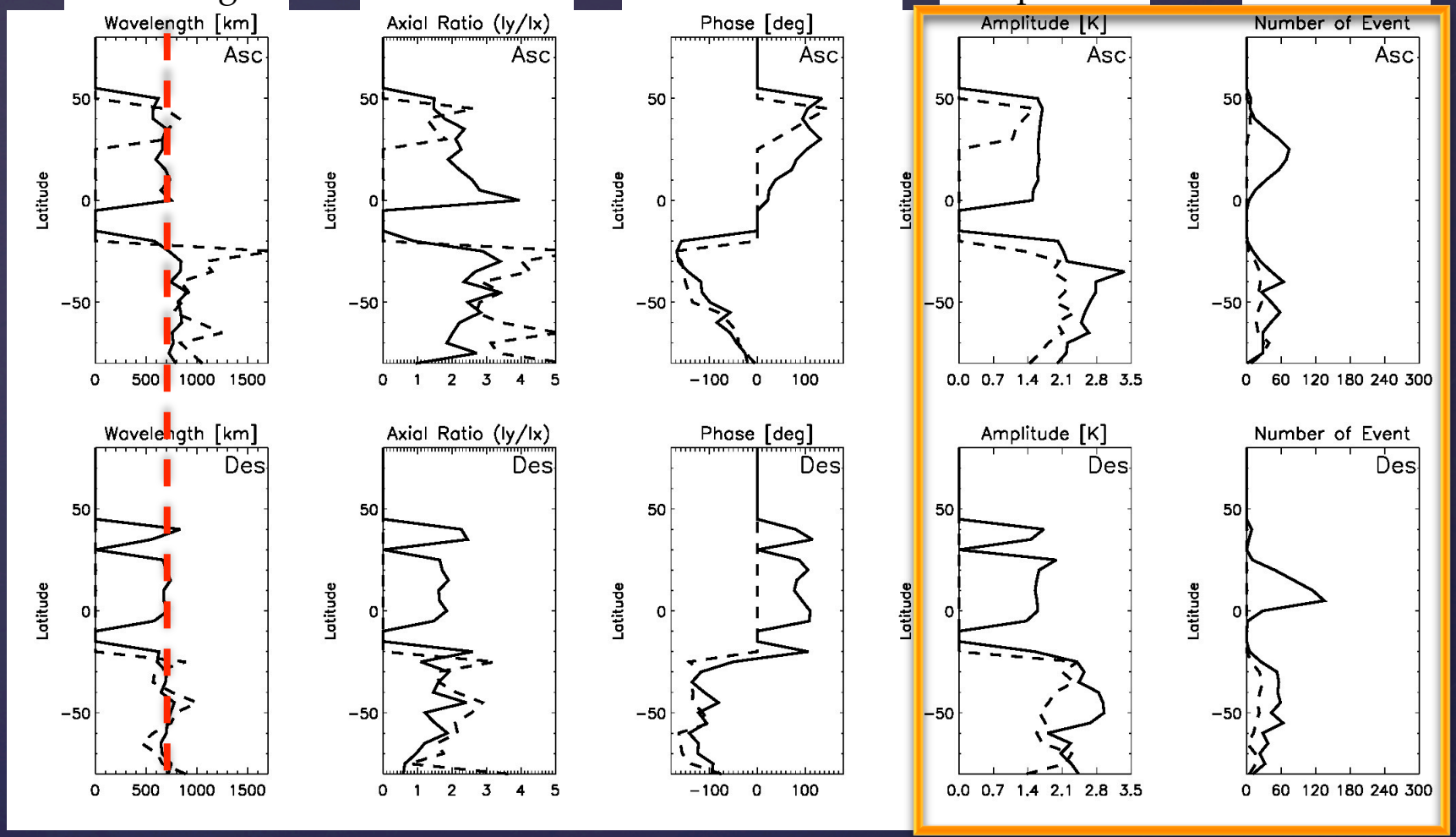
AIRS
ECMWF



- ECMWF resolved CGW has amplitude of ~ 1/3 of AIRS obs.
- ECMWF CGWs occur more often to compensate the amplitude discrepancy.

July, 2010 (T1279)

AIRS
ECMWF



- Increasing model resolution help better resolve CGWs
- Convective CGW is still much less in ECMWF
- CGW is larger during January than July in AIRS obs.

Conclusions for AIRS Concentric Gravity Wave

- We can identify concentric ring patterns from AIRS images. The ring wave amplitude, phase propagation direction, along-track (y) and cross-track (x) wavelengths can be retrieved from the image.
- These ring waves are most prominent above tropical and summer hemisphere active convection and polar-night jet regions.
- Meridional oblique propagation is important. Rings always tend to propagate into the jet centers during day-time, but less apparent in the night-time.
- Concentric ring wavelength has a seasonal cycle.

Conclusions for ECMWF resolved CGWs

- High-resolution ECMWF analysis does a fantastic job in mimicking the observed ring wave properties quantitatively.
- However, ECMWF ring waves do not perfectly resemble the reality. Rings are weaker and slimmer. Weaker GWs are compensated by more occurrence.
- Convective CGWs occur much less often than observed. -> CGW spectrum is skewed toward sub-grid scale parameterized part.
- Increasing model resolution does help model resolving CGWs better.

Future works

- What source mechanism is responsible for ring waves along the polar-night jet (ray-tracing needed)?
- Most of the concentric ring waves can propagate into the mesosphere. How do they tie to mesospheric circulation? How does it affect ionosphere meteorology? (NPP VIIRS can add a particular help)
- Summer ring waves above US and China may enhance troposphere-stratosphere exchange of atmosphere constituents.

Details of this presentation can be found in *Gong et al. (2014, JGR, under review)*

References

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Thank you!